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Current status of an Optically-Segmented Single-Volume Scatter Camera for Neutron Imaging

27th International Nuclear Physics Conference

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on behalf of the SVSC collaboration

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Overview

- Motivation
- Detector description
- Double-scatter neutrons image reconstruction concept
- Single bar characterization
  - Setup using ^{22}Na
  - Setup using ^{90}Sr
- Bar characterization results
- Challenges in the current array
- Alternative array & results
- Muons
- Conclusions

Motivation

- Detection and imaging of neutrons

- Special nuclear material detection
- Nuclear waste handling
- Fundamental particle physics
- Astronomy

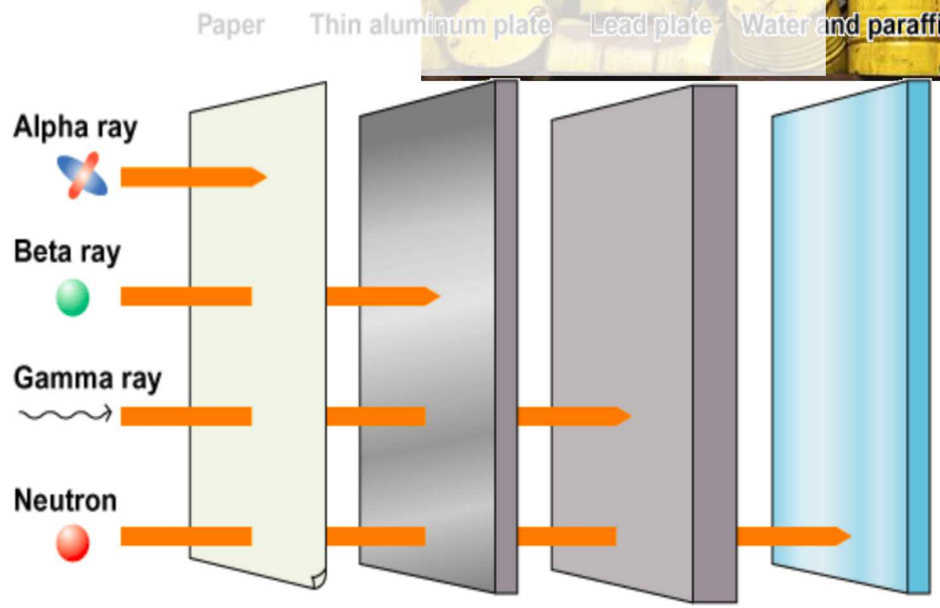
- Fast neutrons:

-Low natural backgrounds

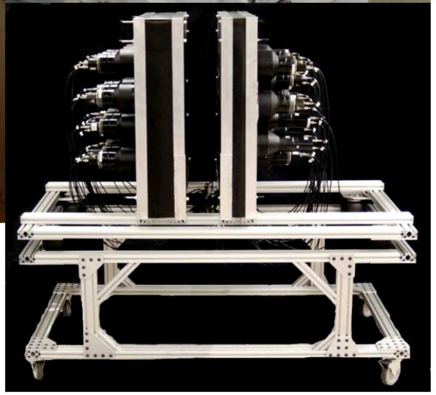
-Ability to penetrate shielding materials

- Desirable:

compact imager, easy to transport and deploy, with a high efficiency.



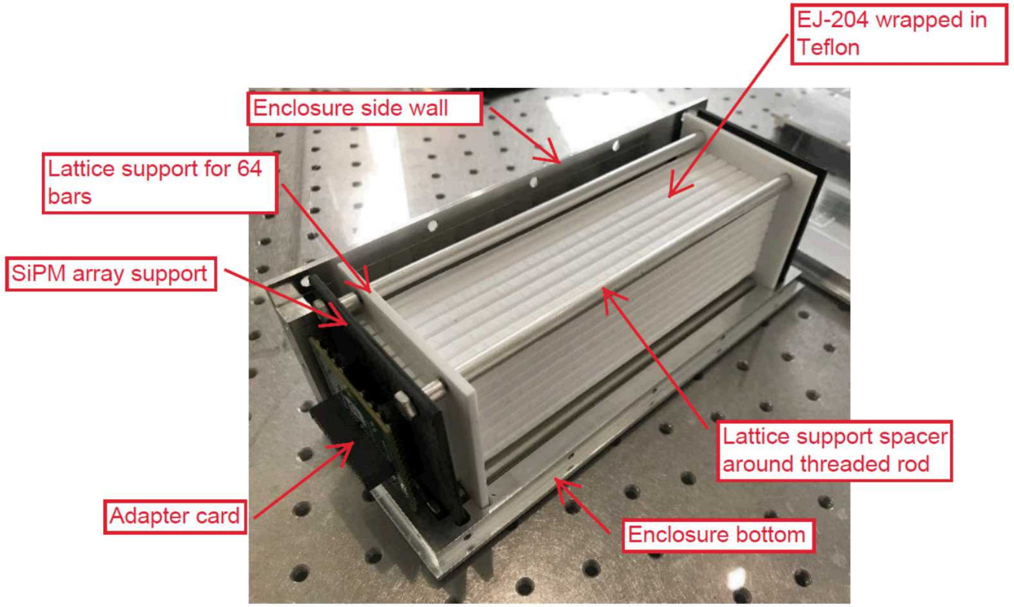
www.remnet.jp

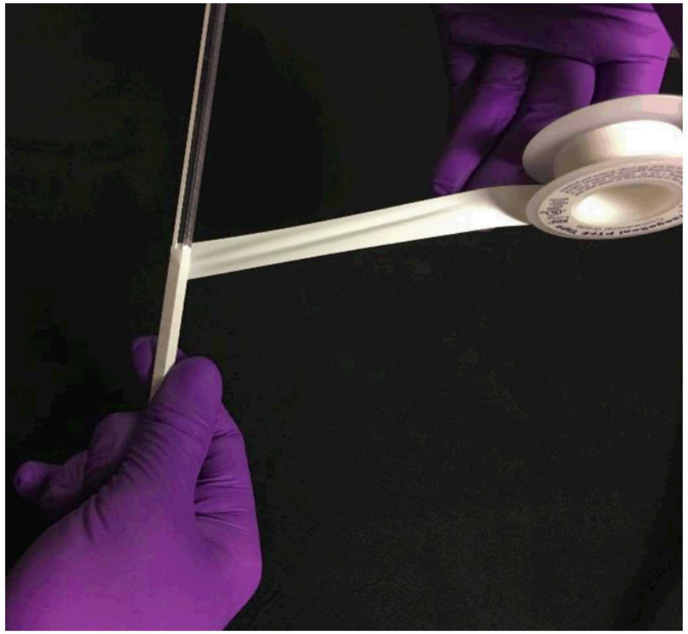


Traditional neutron scatter cameras

Detector description

- 64 5x5x20 mm bars of EJ-204 scintillator, wrapped in Teflon tape
- Two SensL J-series 6x6 mm silicon photomultiplier (SiPM) arrays
- Customized DAQ, which uses 32 IRS3d ASICs, developed at UH

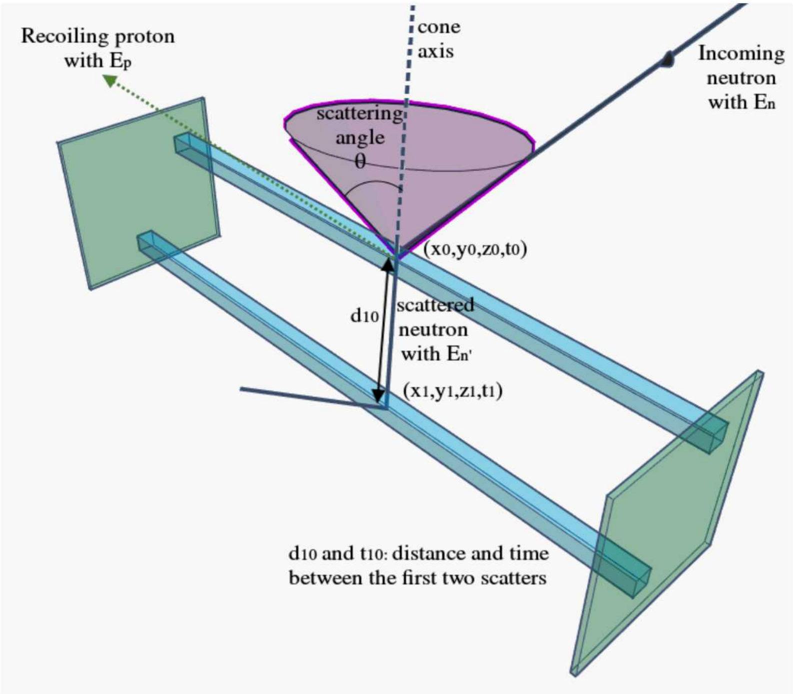




IRS PARAMETERS

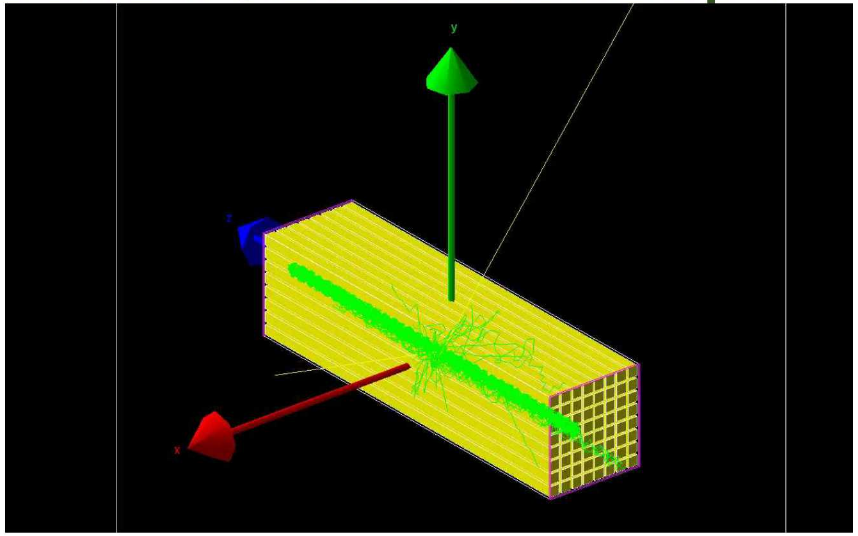
Parameter	Table Column Head
Channels	8
Sampling cells	128
Storage depth	32,786
Digitization	on-chip Wilkilson
Quantization	12(9)-bits logged (effective)
Dynamic range	~ 2 V
Typical noise	$\sim 1\ mV_{RMS}$
Sampling rate	1-4 GSa/s
Buffer time	(8-32)μs
Conversion time	$>2\mu$s

Double-scatter neutrons image reconstruction concept



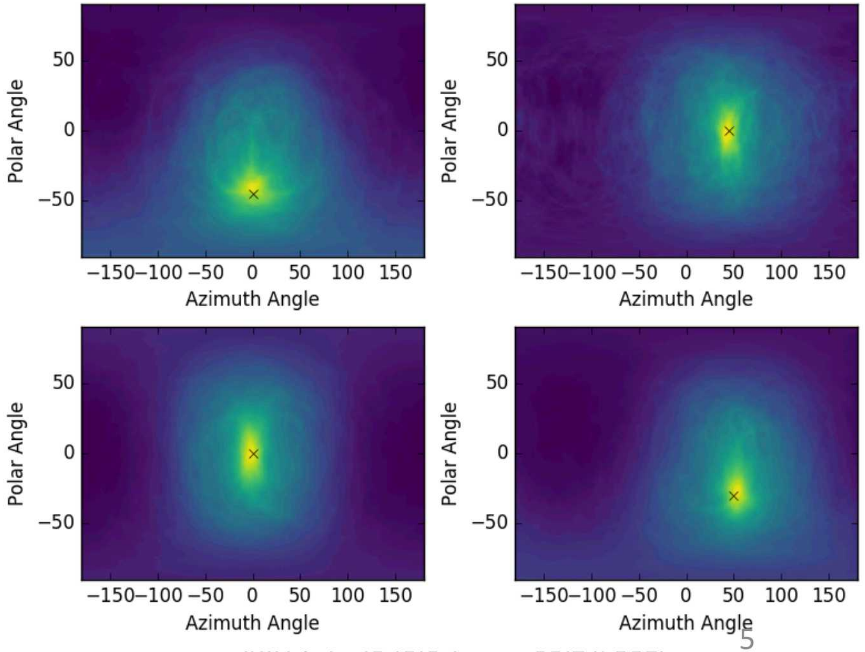
$$E_n = E_{n'} + E_p$$

$$E_{n'} = \frac{1}{2}m_n v^2 = \frac{1}{2}m_n\left(\frac{d}{\Delta t}\right)^2$$



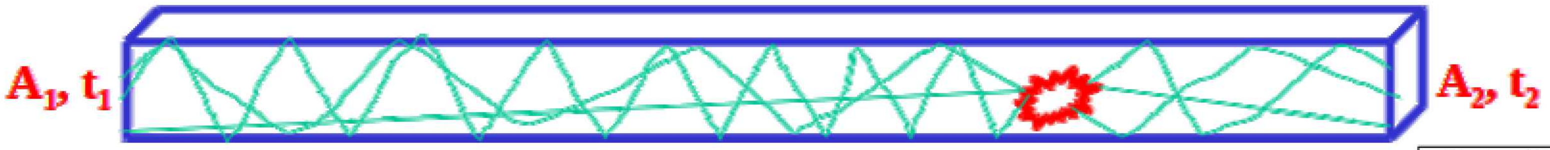
Direction reconstruction via cone back-projection accurately determines simulated source location:

$$\cos\theta = \sqrt{\frac{E_{n'}}{E_n}}$$



(NIM A doi:10.1016/j.nima.2017.11.025)

Single bar characterization



$$z \sim t_1 - t_2 \text{ or } z \sim \log(A_1/A_2)$$

$$t \sim \frac{t_1+t_2}{2}$$

$$E \sim \sqrt{A_1 A_2}$$

Two independent experimental setups performed characterization of the test bars:

- 5x5x190 mm^3 of test scintillator bars
- Test bar coupled to two SensL J-series 6x6 mm^2 SiPM, biased at +30 V
- Data acquired with three DRS4 Eval board, calibrated at 5.12 GHz sampling.

Considered scintillators:

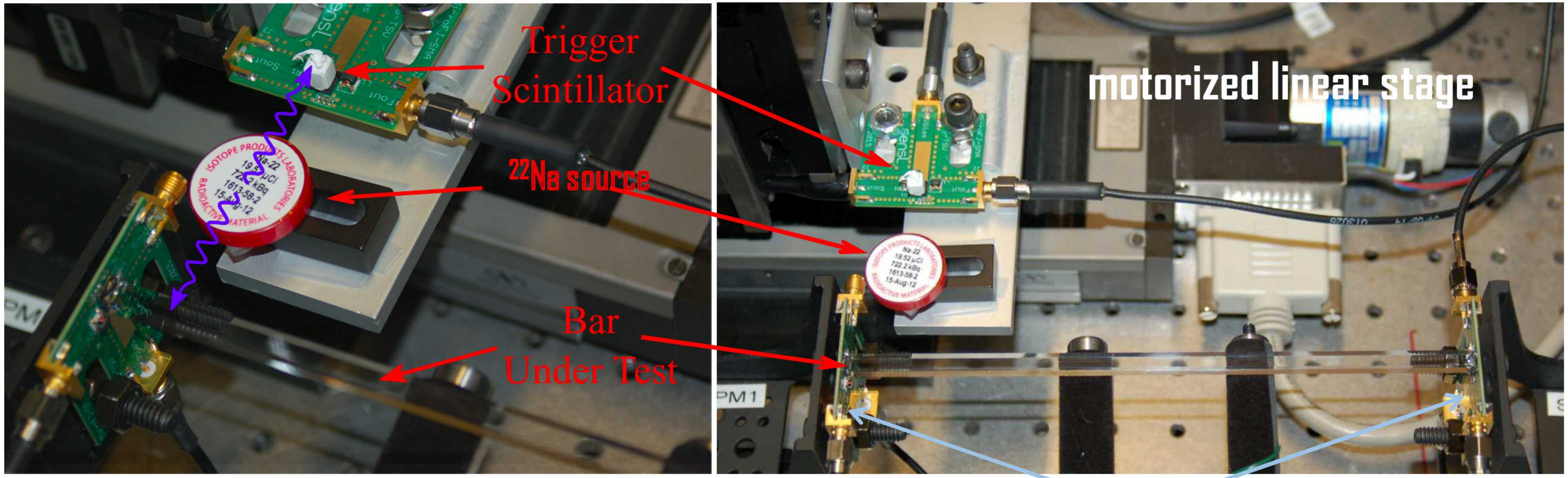
Scintillator	t_R (ns)	λ (cm^{-1})	N_e (MeV^{-1})	N_D (MeV^{-1})
EJ-200	0.9	380	10,000	4,905
EJ-204	0.7	160	10,400	5,084
EJ-208	1.0	400	9,200	4,378
EJ-230	0.5	120	9,700	4,557
EJ-232	0.35	-	8,400	3,679
EJ-260	-	350	9,200	3,470
EJ-262	-	250	8,700	3,548
EJ-276	-	-	8,600	4,203
EJ-276G	-	-	8,000	2,991

scintillator candidates from Elijen Technology

Considered surface reflectivities:

- Enhanced Specular Reflector(ESR)
- PTFE (Teflon) tape
- no surface treatment with only total internal reflection

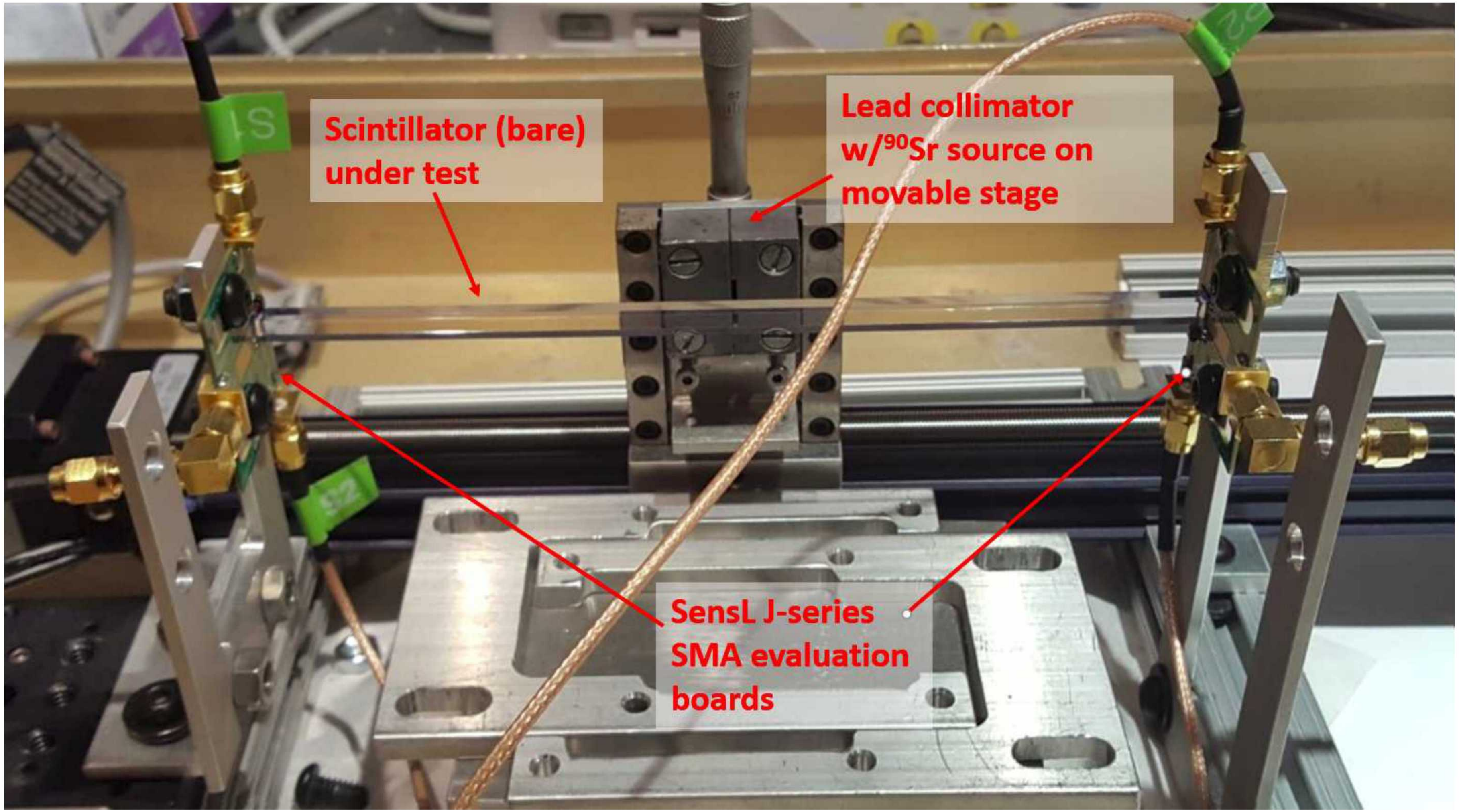
Setup with ^{22}Na source



SensL J-series SiPMs readout

- back to back 511 keV annihilation gammas emitted from a ^{22}Na source.
- Trigger system: 5x5x5mm^2 stilbene crystal, wrapped in Teflon coupled with a single SensL J-series 6x6 mm^2 SiPM.
- Trigger moves along the test bar
- 100,000 events acquired per source position

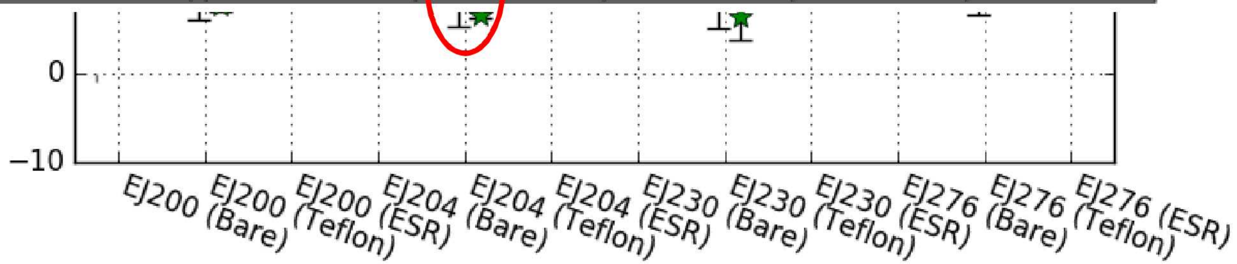
Setup with ^{90}Sr source



- 90 Sr source (betta-emitting)
- Lead collimator limits the betas position under 2 mm, mounted on a scan.
- The system triggers itself on a coincident signal threshold of 7 mV
- 4000 interactions per source position

Single bar characterization results

Scintillator	σ_t (ps)	σ_z (mm)		σ_E/E (%)	
		^{22}Na	^{90}Sr	^{22}Na	^{137}Cs
EJ-200, bare	155±2	13.35	14.27	16.7	14.1
Teflon	154±3	10.29	7.65	14.5	15.8
ESR	145±3	11.14	12.09	16.6	12.2
EJ-204, bare	136±3	10.08	10.67	15.7	14.7
Teflon	**142±2**	**8.06**	**6.54**	**13.1**	**14.3**
ESR	125±3	8.59	9.64	17.6	12.2
EJ-230, bare	141±3	9.61	8.86	17.8	15.0
Teflon	142±2	8.39	6.32	22.6	13.9
ESR	156±3	10.17	8.52	23.4	13.0
EJ-276, bare	183±5	12.13	13.51	17.8	14.1
Teflon	171±2	9.29	9.54	16.5	14.1
ESR	177±4	11.65	10.45	15.0	11.3
Syst. error	±7	±0.73	±0.42	±3.5	-



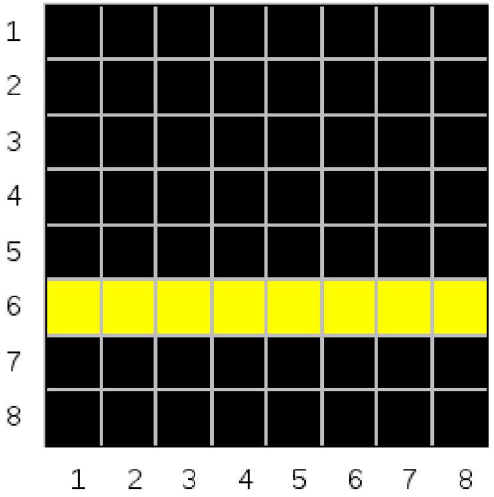
- Agreement between both experimental setups, despite the difference in the configurations.
- The time variable is more robust than the variable of amplitude.
- EJ-204 was selected over EJ-230 given the lowest detection threshold, desirable for fission spectrum.
- Threshold of ~30 ke Vee expected

(NIM A DOI:10.1016/j.nima.2019.02.063)

Achievements and challenges in the current array

The optically segmented single-volume scatter camera prototype

Pixels illuminated by cosmic muons in one SiPM of the detector



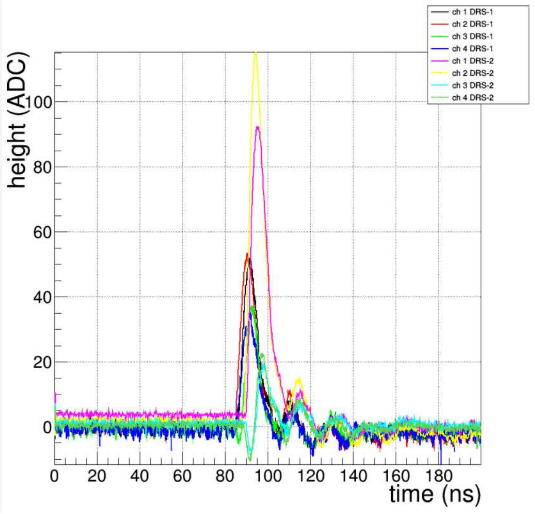
- Full array assembled

- Full electronic system testing is underway

- Crosstalk found in the signals

Crosstalk correlation among the SiPM pixels, the red pixel corresponds to the channel illuminated by a laser, the color represents the amplitude of the crosstalk.

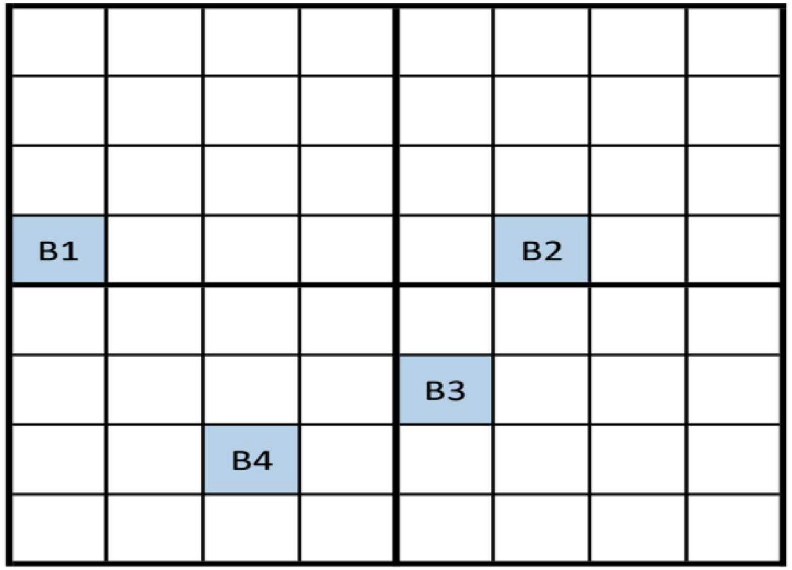
Waveform signal with crosstalk:



Alternative carried out test

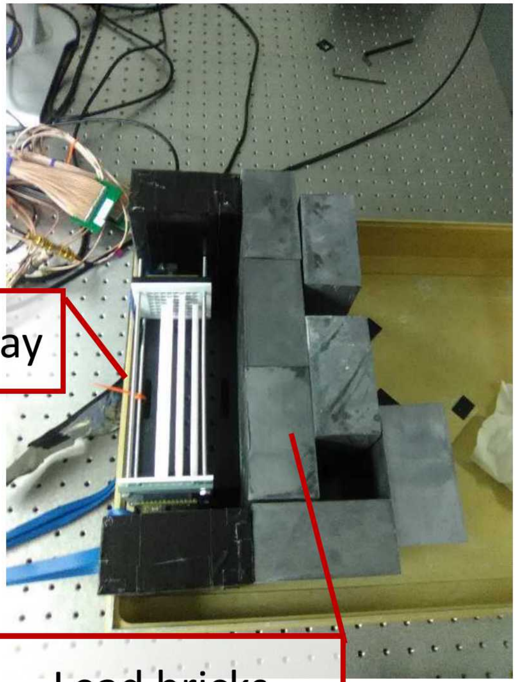
Alternative array, consistent with the prototype (0.5 x 0.5 x 19 cm^3, EJ-204 wrapped with Teflon, two readout SensL J-series 6x6 mm^2, DRS4 daisy chain), filled with four bars placed as follows:

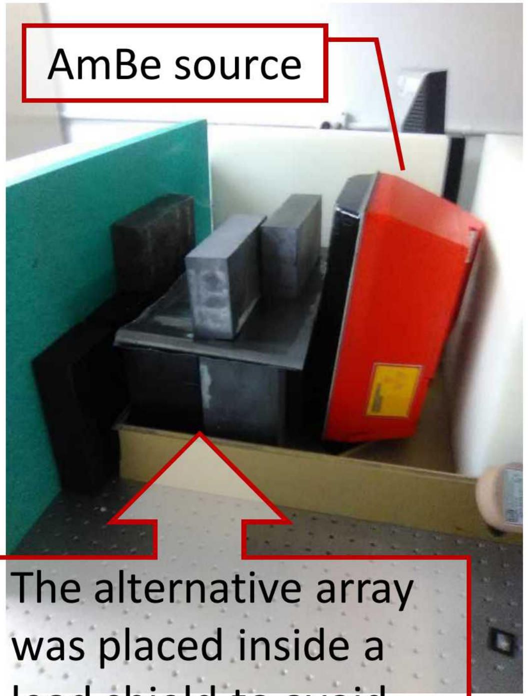
Bar Assignment (L)



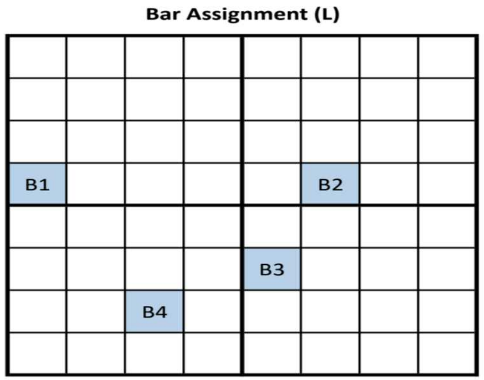
in order to avoid most of the electronic crosstalk detected in the full array.

- B1 as target for neutron scatters
- B2, B3, and B4 set as targets for the second neutron scatter.
- Trigger condition: pulse of at least one bar end over threshold, between bars 1&2 or 1&3 or 1&4
- Threshold: 5mV



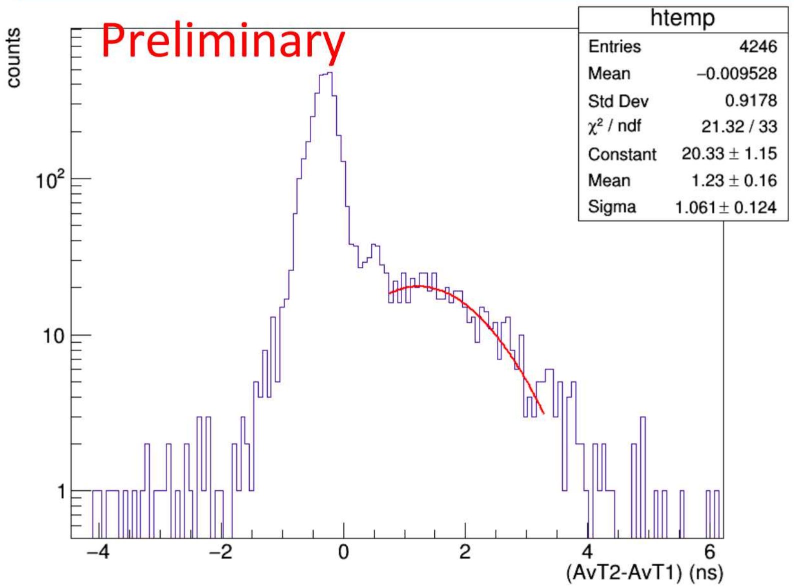


- The alternative array was placed inside a lead shield to avoid gammas.



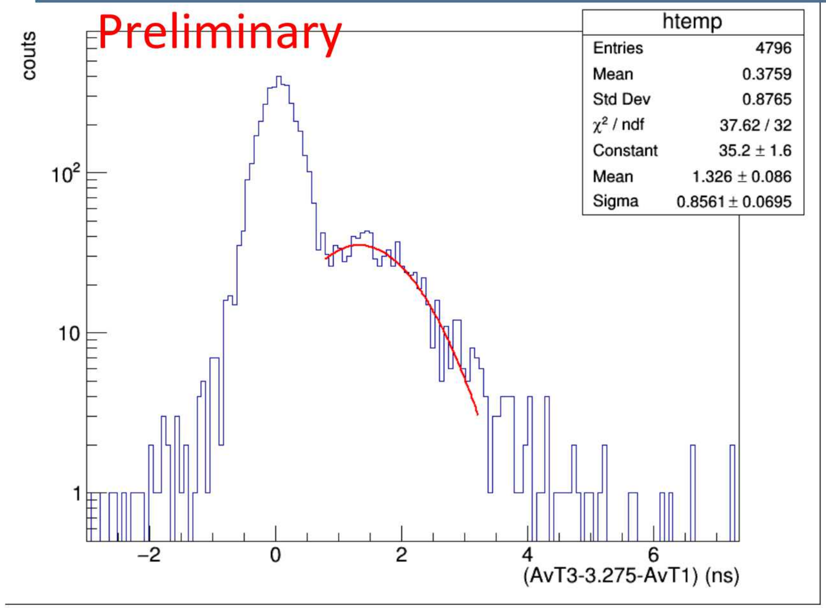
Results of neutron double-scatters, using the AmBe source

- average time difference between bars 1 & 2



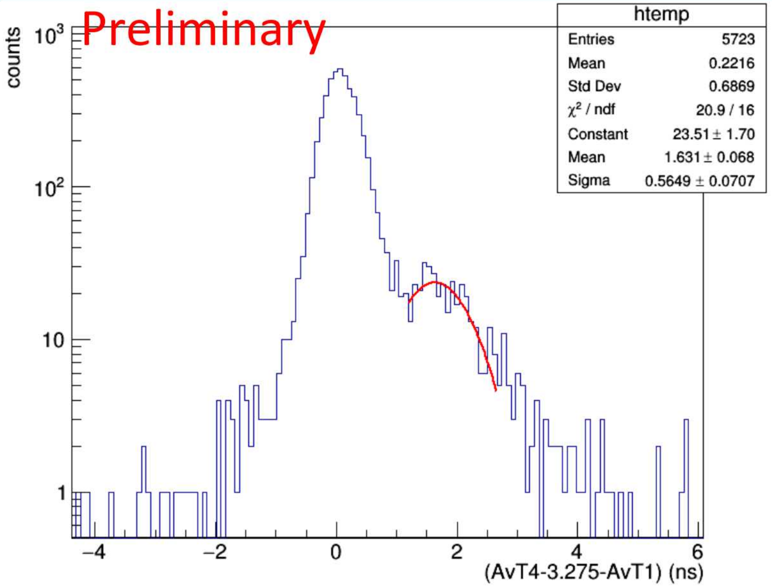
Min distance:
$|X_{Bar1-Bar2}|$=3.165 cm
ΔV~2.57 cm/ns
Max distance:
$|X_{Bar1-Bar2}|$=3.319 cm
ΔV~2.698 cm/ns

- average time difference between bars 1 & 3



Min distance:
$|X_{Bar1-Bar3}|$=2.83 cm
ΔV~2.134 cm/ns
Max distance:
$|X_{Bar1-Bar3}|$=3.002 cm
ΔV~2.2639 cm/ns

- average time difference between bars 1 & 4

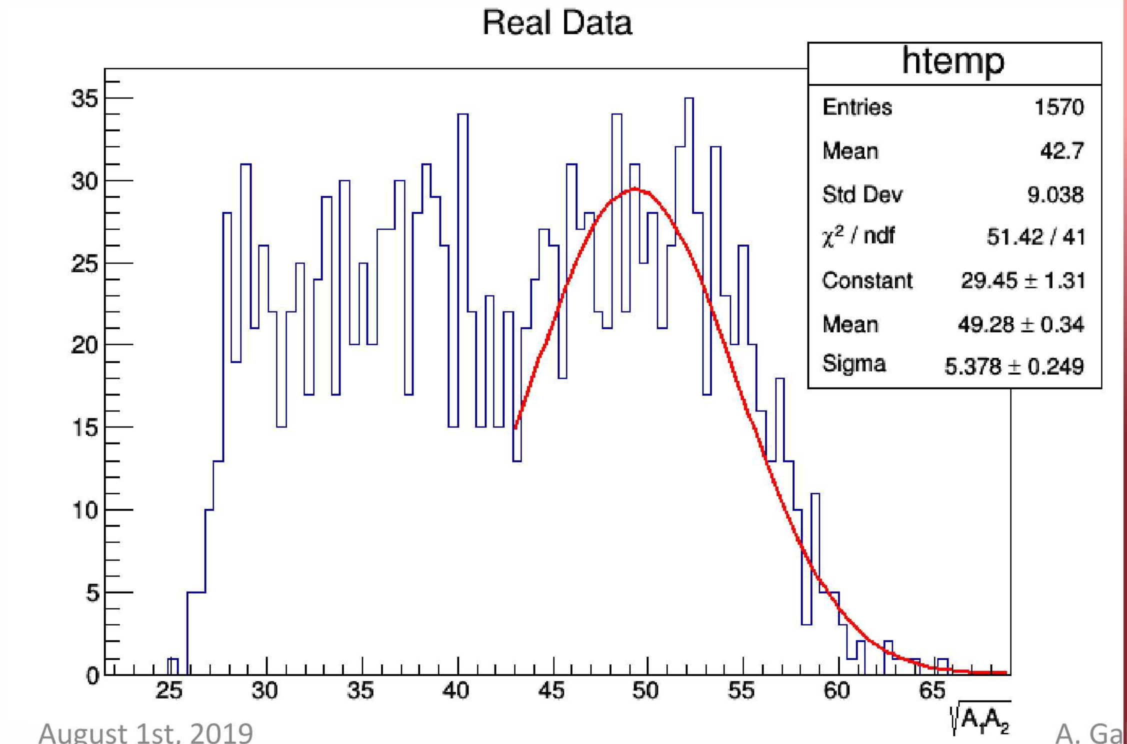


Min distance:
$|X_{Bar1-Bar4}|$=2.282 cm
ΔV~1.399 cm/ns
Max distance:
$|X_{Bar1-Bar4}|$=2.491cm
ΔV~1.527 cm/ns

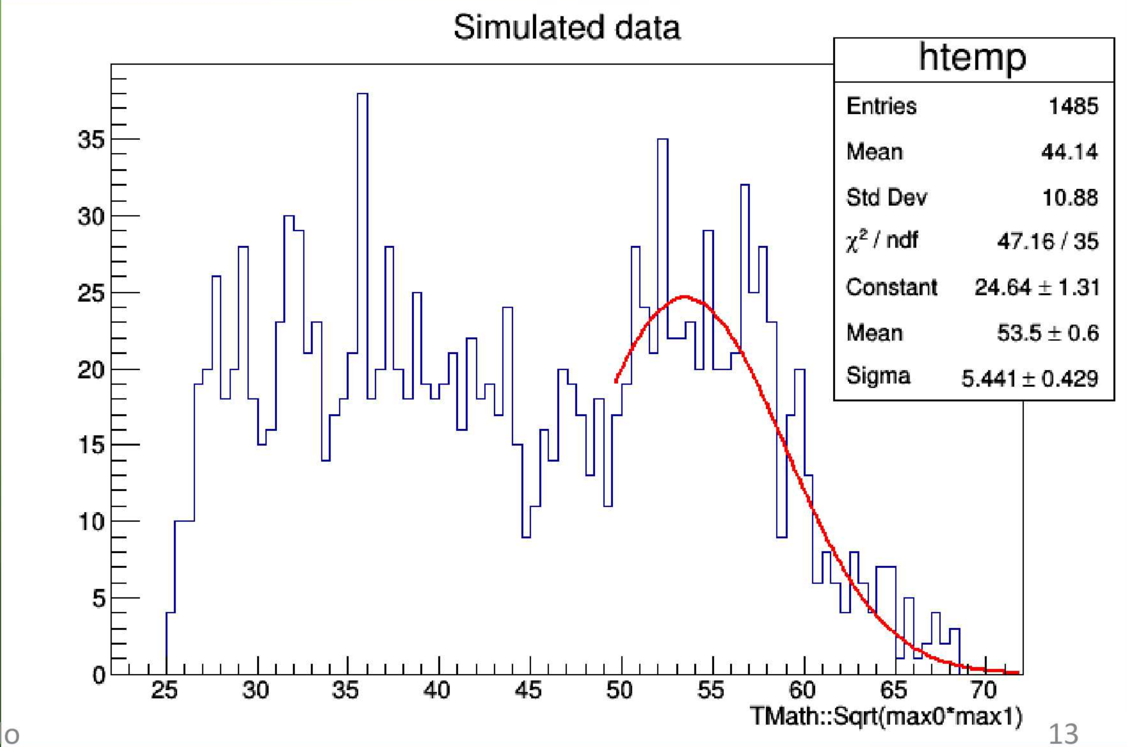
Test bar simulations

- SiPM simulations using Monte-Carlo based on GosSiP[1] framework, which provides a detailed model of the SiPM response
- Light source. Information needed from photons arriving at the SiPM area in each SimEvent:
  - ▲Position x,y
  - ▲z position (sensitive volume name)
  - ▲time
  - ▲wavelength (Energy)
- Data acquisition. Simple simulation of the basic characterization measurements.
- SiPM parameters customized. The signal charge and the waveform are simulated for specified parameters.

Data of an EJ204 bar wrapped with Teflon, ^{157}Cs source at 2 cm from the center:



Simulation of an EJ204 bar wrapped with Teflon, ^{157}Cs source at 2 cm from the center(GEANT4 + GosSiP):



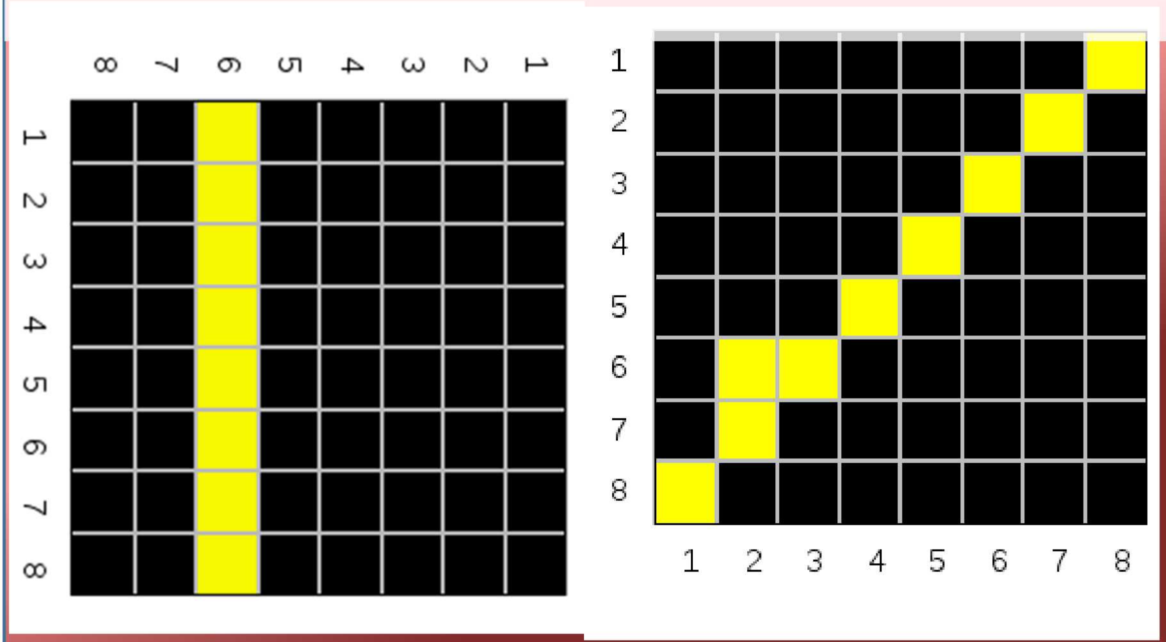
[1] http://www.kip.uni-heidelberg.de/hep-detektoren/gossip

Simulation and real data for muons

Preparing the detection/calibration using muons, with simulations and real data

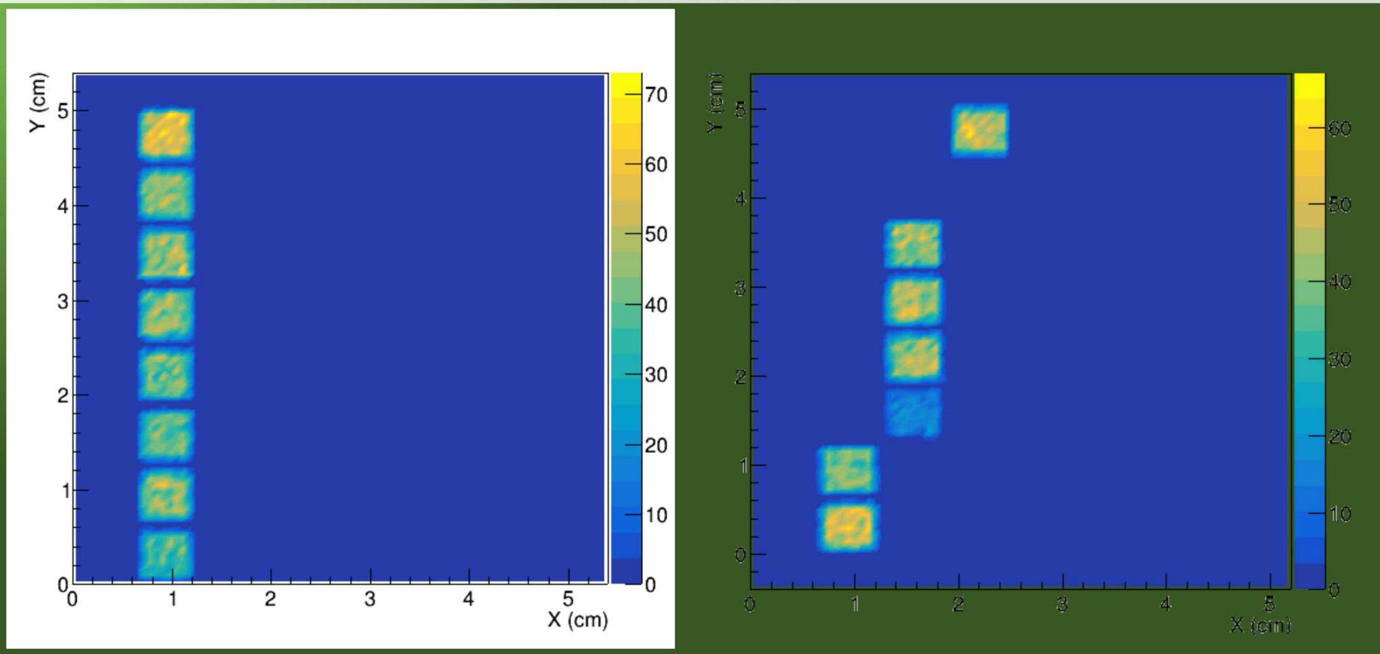
Real data

- Muons detected in one side of the array, using the IRS3D
- Pixels illuminated when passed a threshold

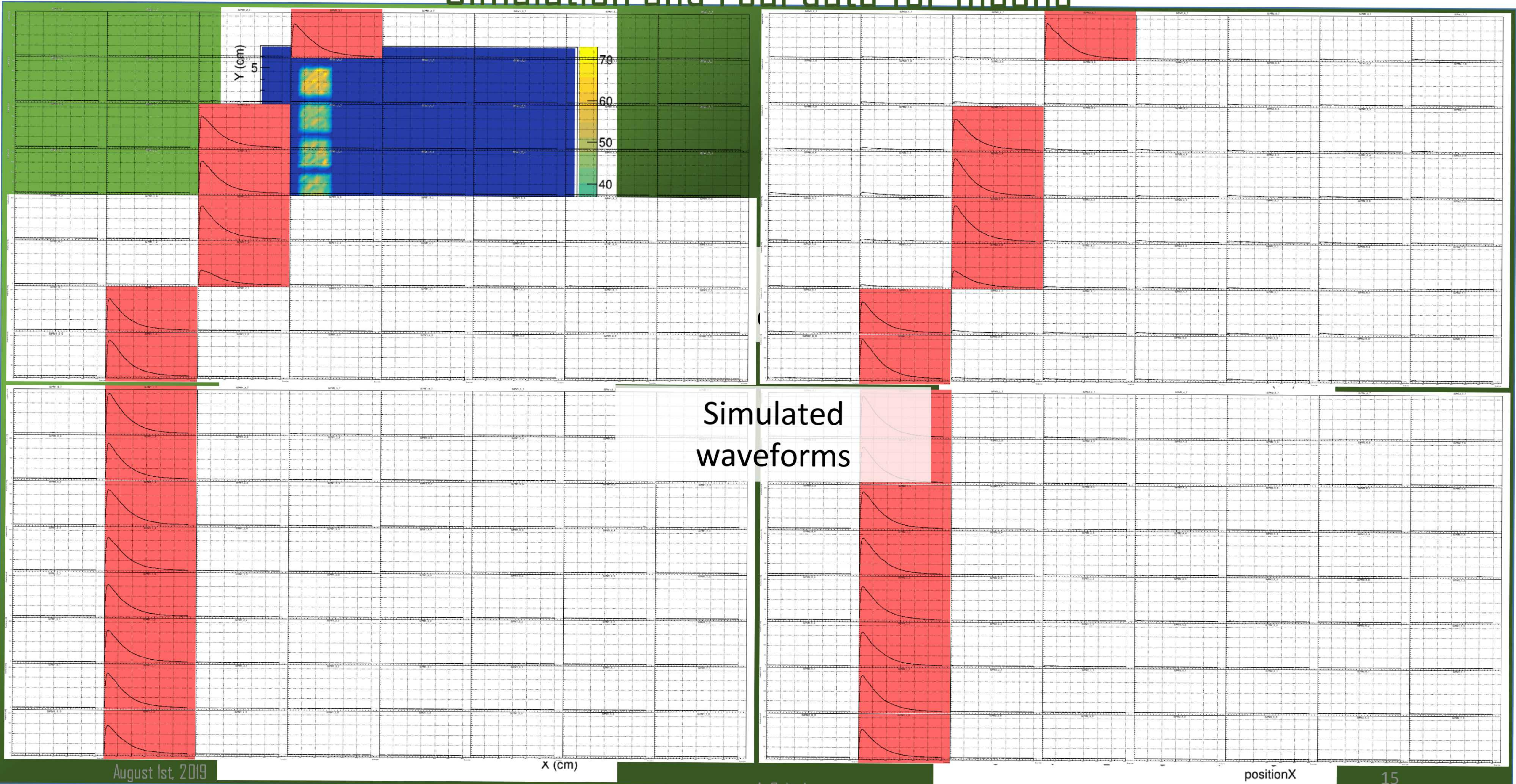


Simulated data

- Full detector array programed in Geant4
- Cosmic muons generated using CORSIKA, randomly distributed on the top of the array
- Photons detected in the SiPMs volumes



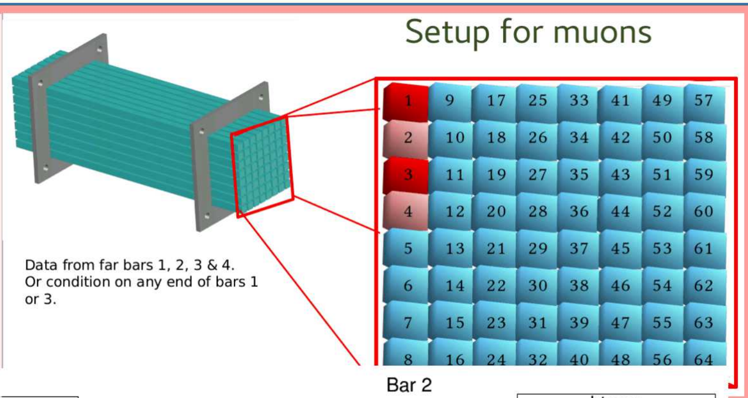
Simulation and real data for muons

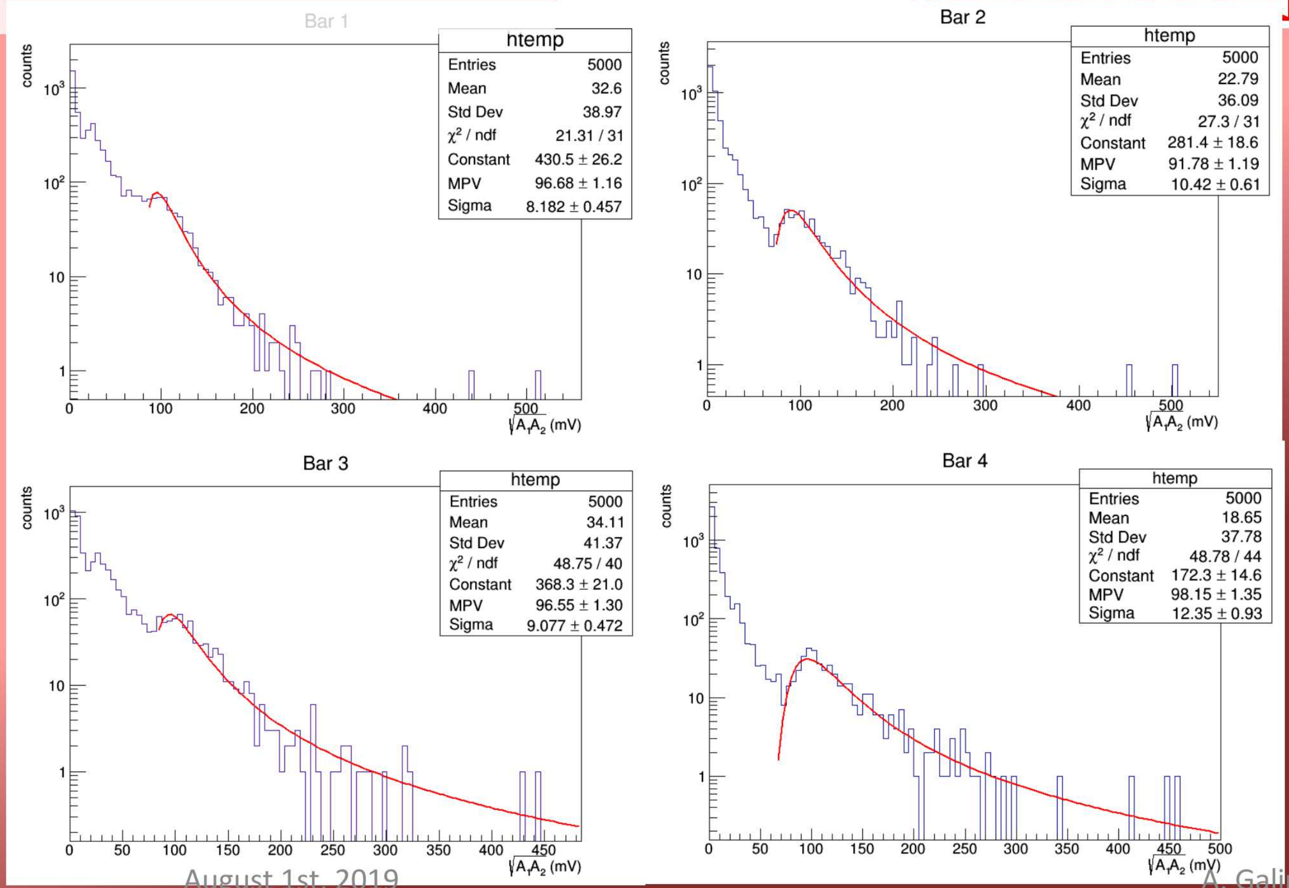


Simulation and real data for muons

Real data

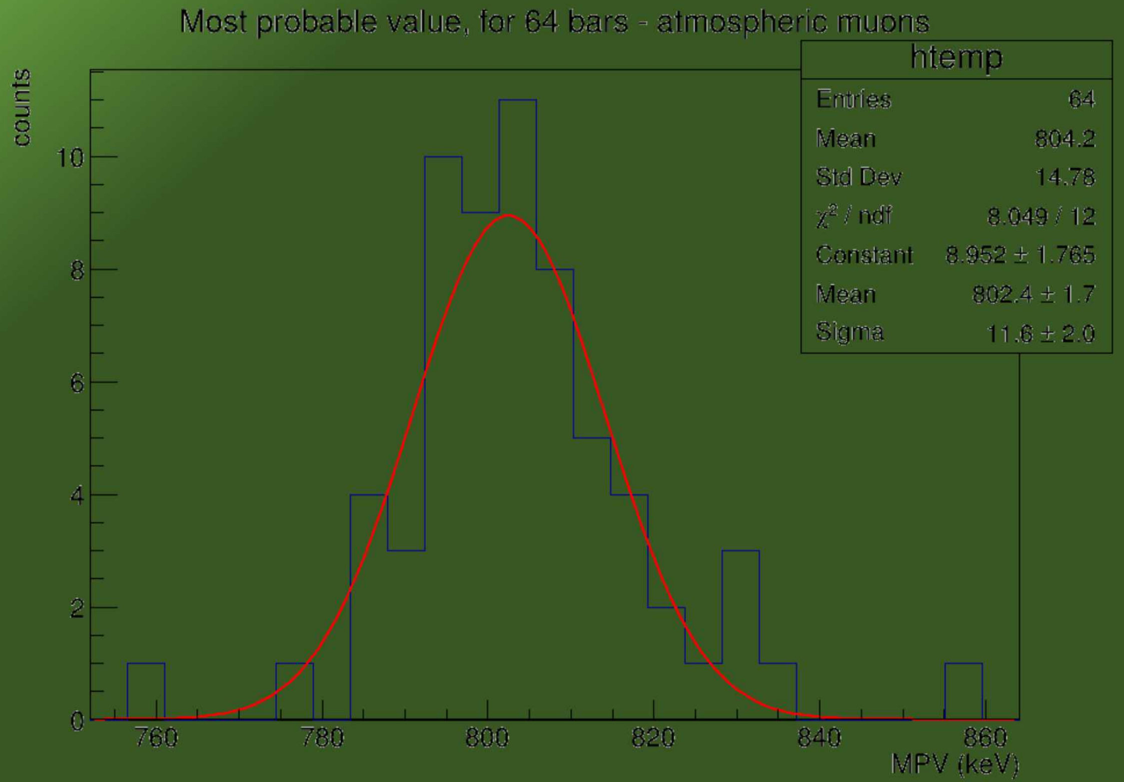
- 4 bars of the full detector
- acquisition with 2 DRS4 daisy chain
- Amplitude histograms:





Simulations

- Histogram of the most probable value for the 64 bars
- simulations of 5000 vertical incident muons



Conclusions

- Optical coupling, trigger conditions, covering and optical quality of bars all affect amplitude (Δz & ΔE) and must be controlled and calibrated.
- Time measurements are more robust against systematics than amplitude
- We can achieve ~1cm spatial resolution
- We're able to see neutron double scatter events
- Muons and neutron simulations undergoing, including waveforms.
- Directional resolution soon to be measured.

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Thank you!